Carbon Capture and Storage

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Geological storage of carbon dioxide

IEA: 40 Gt CO₂
<2% of Emissions to 2050

Parson & Keith:
370-1100 Gt CO₂

IEA: 920 Gt CO₂
45% of Emissions to 2050

Parson & Keith:
740-1850 Gt CO₂

IEA: 400-10 000 Gt CO₂
20-500 % of Emissions to 2050

Parson & Keith:
370-3700 Gt CO₂

Source: Freund, IEA - Comparative potentials at storage costs of up to $20/t CO₂

736 Gt in North Sea alone (DTI)
Why geological storage?

• Technology already established – many carbon dioxide injection projects in the world.
• Allows smooth transition away from a fossil fuel economy.
• Economic benefit of enhanced oil recovery.
• Has potential to have a large impact on carbon dioxide emissions quickly.
• Low emission option for developing countries – e.g. China and India who will invest in coal-burning power stations anyway.
Current projects – planned or underway

Source: Peter Cook, CO2CRC
Current oil field projects

- 66 CO\(_2\) injection projects worldwide.
- Many in West Texas.
- Uses natural sources of CO\(_2\) from underground reservoirs.
- Extensive pipeline infrastructure.
Sleipner project

Source: Holloway, Review of the Sleipner Project

250 km offshore – production started in 1996
Sleipner project (continued)

- 1 million tonnes CO$_2$ injected per year.
- CO$_2$ separated from produced gas.
- Avoids Norwegian CO$_2$ tax.
- Gravity segregation and flow under shale layers controls CO$_2$ movement.
Time lapse (4D) seismic tracking of injected CO₂

Block diagram to illustrate the principle of CO₂ deposition. Unwanted CO₂ produced with the gas from the Sleipner field gas reservoir is injected into the Utsira formation for storage. The 1999 and 2001 time-lapse seismic sections (lower right) show that the injected CO₂ is in place and that the volume has increased substantially - a fact which is further corroborated by the corresponding seismic amplitude maps (upper right).
Issues to address

• How to separate carbon dioxide from the exhaust stream of a coal or gas-burning power station efficiently.
• Investment in pipeline infrastructure.
• Will the carbon dioxide remain underground?
  – Where will the carbon dioxide go and how can it be monitored?
  – Integrity of the geological seal
  – Leakage through wells
  – Long-term fate, including geochemical reactions
Post-combustion capture

(IEA GHG www.ieagreen.org.uk)

Natural Gas → Gas Turbine → Air

N₂, O₂, H₂O to Atmosphere

CO₂ Capture → CO₂ to Storage

Steam Generator

Steam Turbine
Carbon dioxide properties

- Critical point of CO$_2$ is 31°C and 72 atm (7.2 MPa).
- CO$_2$ will be injected deep underground at supercritical conditions (depths greater than around 800 m).
- CO$_2$ is relatively compressible and its density, although always less than water is typically less than oil.
- Low viscosity – typically around 10% that of water.
Issues associated with reservoir injection

- CO₂ can become miscible with the reservoir oil – critical pressure called the MMP (minimum miscibility point).
- Wherever the CO₂ goes all the oil is recovered – very effective recovery process.
- Problem is that CO₂ tends to channel along high permeability streaks – low sweep efficiency.
CO$_2$ injection in the North Sea

- Ideal opportunity: light oil (reservoir pressures typically above the MMP), mature fields, nearby sources of CO$_2$.
- At least 3 billion barrels of extra oil could be recovered in theory.
- Known well-characterised geological traps.
- Pipeline infrastructure and few, known wells.
- UK Government backing of CO$_2$ sequestration in recent energy white paper.
- Experience with gas injection in the North Sea (but not CO$_2$!); CO$_2$ injection elsewhere.
UK carbon emissions by sector

Some numbers

- Current emissions are around 25 Gt CO₂ per year (6 Gt carbon).
- Say inject at 10 MPa and 40°C – density is 700 kgm⁻³.
- This is around 10⁸ m³/day or around 650 million barrels per day. Current oil production is around 80 million barrels per day.
- Huge volumes – so not likely to be the whole story.
- Costs: $6 – 200 per tonne CO₂ injected.
- 1-3p/KWh for electricity for capture and storage.
- Could fill the UK emissions gap in 2020 easily.
What can we do at Imperial?

• Work on new technologies.
• Lobby Government and engage with oil companies.
• My expertise – multiphase flow in porous media and reservoir simulation.
• The principal issue affecting CO$_2$ injection is determining where it goes – governed by geology, multiphase flow properties and gravitational forces.
• Develop novel simulation methods suitable for the study of such problems.
Overview of the streamline method

Permeability field

Pressure solve

Saturation along SL

Initial saturation

SL tracing

Saturation for the next time step
Saturation update

Initial saturation (irregular mesh)

Final saturation (irregular mesh)

Initial saturation (regular mesh)

Final saturation (regular mesh)
1D simulations

1D simulation. Inject for 20 years then 180 years of groundwater flow. Advection only.
1D simulations (cont.)

1D simulation. Inject for 20 years then 180 years of groundwater flow. Advection and dissolution.
1D simulations (cont.)

1D simulation. Inject for 20 years then 180 years of groundwater flow. Advection and dissolution and reaction.
3D simulations

1 million cell representation of North Sea Field (SPE 10 case). Permeability field.
Horizontal slice - advection

Simulation of sequestration. CO$_2$ saturation shown.

20 years

200 years
Vertical slice - advection

Simulation of sequestration. CO$_2$ saturation shown.

20 years

200 years

200 m

4800 m

0 0.8 Saturation
Vertical slice - dissolution

Simulation of sequestration. CO₂ saturation shown.

20 years

200 m

200 years

200 m

4800 m

0 0.8 Saturation
Vertical slice - dissolution

Simulation of sequestration. CO$_2$ concentration shown.
Vertical slice - reaction

Simulation of sequestration. CO\textsubscript{2} saturation shown.

20 years

200 years

200 m

4800 m

0 Saturation 0.8
Vertical slice - reaction

Simulation of sequestration. CO$_2$ concentration shown.
Vertical slice - reaction

Simulation of sequestration. Porosity shown.

20 years

200 m

200 m

4800 m

0.13 Porosity 0.15

200 years
Mass in each phase

Study how much mass is in which phase. Sequestration efficiency around 2 – 3 % only.
Streamline recap

• Ideal method for handling initial injection phase – complex thermodynamics and reservoir heterogeneity combined.
• Can handle rate-dependent mass transfer – fractures or reaction chemistry.
• Readily study large, finely gridded models.
• Huge uncertainties in geochemical characterisation.
Overview

• Carbon capture and storage is a key component to reduce atmospheric CO$_2$ emissions.
• UK has a strategic opportunity to take a lead in CCS.
• Unique combination of fossil-fuel burning power stations close to oil fields ripe for CO$_2$ flooding plus pipeline infrastructure.
• Main issues to predict where the fluid moves (characterisation and simulation), monitor where the fluid moves (4D seismic) and long-term fate (geochemistry, dissolution.)
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